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We have worked on a number of different projects relating to visual perception and memory for features and objects, exploring the processing that converts visual sensory data to representations of objects and events. An important focus has been to define the role played by attention in this processing and in the memory representations which result. I divide this report into four main sections: One deals with studies of relatively early visual processing of features; another with the role of attention in feature integration; another major project explores the effects of the initial perception of novel objects on their reperception, either immediately, after a single presentation, or after multiple trials or long delays, using negative priming tasks to explore the memory traces formed for novel objects, both with and without attention; the final section explores the notion of object tokens in the context of perceptual learning and priming in visual search automatization.

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Final Report: Visual Perception and Memory for Objects.
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University of California, Berkeley
(Now at Princeton University)

General Organization

The people employed by the grant were Amy Hayes as technical assistant until July 1992, Ephram Cohen as part-time programmer, Irina Rivkin and Anne Pugh as undergraduate lab assistants, Julia Simovsky and Heather Rose (at different times) as clerical assistants, Brett De Schepper, Marcia Grabowecky, Todd Horowitz, Beena Khurana, Kathy O'Craven, and Meg Wilson (at different times) as graduate student R.A.'s. Todd Horowitz is about to submit his doctoral dissertation and the other five have now all obtained the Ph.D. degree.

From September 5th, 1991 to June 1992, I was on leave at the Russell Sage Foundation, New York, and in September 1993 I moved to a permanent position in the Department of Psychology at Princeton University. In the years that I spent away from Berkeley, I returned for the Summer months. For the remaining time, I was in constant communication with my students and assistants by email, as well as paying several short visits to my Berkeley lab in the course of the year.

Research

We have worked on a number of different projects relating to visual perception and memory for features and objects, exploring the processing that converts visual sensory data to representations of objects and events. An important focus has been to define the role played by attention in this processing and in the memory representations which result. I divide this report into four main sections: One deals with studies of relatively early visual processing of features; another with the role of attention in feature integration; another major project explores the effects of the initial perception of novel objects on their re-perception, either immediately, after a single presentation, or after multiple trials or long delays, using negative priming tasks to explore the memory traces formed for novel objects, both with and without attention; the final section explores the notion of object tokens in the context of perceptual learning and priming in visual search automatization.

I. Early visual coding and attention

In this section I outline several different projects that have explored aspects of early visual processing of features, both with attention divided over the display

and with attention focused on particular locations.

1. Preattentive processing and apparent motion, with Todd Horowitz
(see reference 10)

Apparent motion is seen when two similar stimuli are presented in quick succession at some spatial displacements. We perceive one object moving from one location to another, when there is in fact no real motion involved. Braddick (1980) and others (for instance Petersik, 1989) have argued that two separate systems are responsible for the perception of apparent motion. The short-range system, presumed to be based on low-level detectors early in the visual system, is responsible for the perception of real motion as well as apparent motion over short displacements. The perception of motion over larger displacements is assigned to a long-range system. This system is often conceived of as a higher level system, more "cognitive" or inferential in nature. However, there have been few proposals for mechanisms to explain the operation of the long-range system.

We tested the idea that focused attention, in the sense of Feature Integration Theory (Treisman & Gelade, 1980; Treisman & Sato, 1991), is the mechanism responsible for the perception of long-range motion. Recent studies using the visual search paradigm to investigate apparent motion suggest that differences in short-range motion are detected in parallel, as if they were sensed by specialized feature detectors, whereas attention is necessary to create the impression of long-range motion, perhaps because the two successive presentations must be integrated into a unitary percept in the same way as feature integration theory suggests for the different parts or properties of a single object. We replicated results by Ivry & Cohen (1990) and Dick, Ullman, & Sagi (1987), using search for vertically oscillating targets among horizontally oscillating distractors. Time to find targets in the short-range condition was independent of the number of distractors, while RT increased linearly with set size in the long-range condition.

The feature integration account suggests a further prediction. Any factors which rule out the short- range system should also force the use of focused attention in the perception of apparent motion. Anstis & Mather (1975) suggest that one such factor may be reversal of contrast within a stimulus in apparent motion. This would agree with other evidence suggesting that information carried by bicontrast stimuli cannot be extracted preattentively (O'Connell & Treisman, 1991, see section 2 of this report). We looked at search for targets defined by direction of motion, using bicontrast stimuli. Subjects searched for vertically oscillating targets in four conditions created by crossing bicontrast vs. unicontrast stimuli and long vs. short displacements. The unicontrast conditions replicated previous results. Short-range targets were detected in parallel, while long-range performance suggested serial search. However, in the bicontrast conditions, short-range search was seriously disrupted by contrast reversal, forcing the use of focused attention. Search for long range targets, which already required attention in the unicontrast condition, was unaffected by the change to bicontrast displays.

This contrast type X range interaction argues against a unitary explanation of apparent motion perception. However, without examining search rates over a

continuum of intermediate positions, it is difficult to claim a sharp processing dichotomy. The hypothesis therefore calls for converging evidence. If attentive motion detection depends on a different mechanism from the short-range motion detectors, their independence might be demonstrated by selective adaptation experiments. Adapting to short-range motion should leave long-range and bicontrast motion detection unaffected, but should impair search for short range targets. This is what we found. The results are consistent with the idea that short range motion depends on specialized detectors operating in parallel across the display, and subject to selective adaptation, whereas attention is needed to link successive elements when they appear at separations of 3 or more dot widths, or when they are of opposite contrast.

2. Attention effects on the coding of motion: An fMRI study.

Kathy O'Craven (previously O'Connell) has completed her doctoral dissertation, using the fMRI machine at Massachusetts General Hospital under the general supervision of Robert Savoy. The question she investigated was how voluntary attention to one aspect of a visual stimulus affects the neural processing of that stimulus? She examined the magnitude of functional Magnetic Resonance Imaging (fMRI) activation in the putative human homologue of the MT/MST complex, during different attentional conditions. While fixating, the subject viewed a stimulus composed of both moving and stationary dots. During the two critical conditions, the stimulus remained identical but the subject was instructed to voluntarily direct attention to either the moving or the stationary dots and ignore the other set. Between critical conditions, subjects viewed and attended a baseline stimulus containing only stationary dots. The MT/MST complex was localized by statistically testing each voxel for increased activity when subjects viewed the moving and stationary dots versus when they viewed a baseline stimulus consisting of only stationary dots. Kathy then compared the magnitude of activation within this ROI for each image collected in the "attend moving" condition to the magnitude for each image collected during the "attend stationary" condition. For each of three subjects tested, t-tests showed significantly more MT/MST activation ($p < .001$) when the moving dots were attended than when stationary dots were attended, even though the visual stimulus was identical during these two conditions. In contrast, a region in primary visual cortex, which also preferred moving to stationary dots, showed no attentional enhancement effect. This suggests that the observed effect in MT/MST is not due to general arousal or other global factors. The conclusion is that while any moving visual stimulus will activate the MT/MST complex, that activation is stronger when the moving aspects of the stimulus are attended than when the stationary aspects are attended.

This is one of the first studies to demonstrate selective attention effects in a pre-striate visual area using the fMRI brain-imaging technique. Kathy has presented her results at the brain-imaging conference in Paris, June 1995.

3. Coding of orientation, with Kathy O'Craven
(See reference #17)

With Kathy O'Craven, I continued the research on preattentive orientation coding that we began under the last grant. Our main findings can be summarized as follows. Orientation can be carried by a number of different "media," including lines, edges, pairs of dots, and subjective contours. We investigated whether the coding of orientation is shared by different media, using a visual search task for targets defined by conjunctions of a particular orientation and a particular medium. When half the distractors share the target orientation in a different medium they should interfere with target detection if and only if the orientation code is shared by the two media. The results showed substantial effects of display size in search for conjunctions with lines and dot pairs of shared contrast, and with lines and edges, although both orientation and medium could be detected in parallel for targets defined by any one of these features alone. The orientation of bicontrast dot pairs (one black dot and one white dot on an intermediate gray background) could not be detected in parallel. The stimuli that show parallel coding in feature search and interference in conjunction search seem to correspond with those that drive orientation-selective cells in the early visual areas.

We then carried out several additional experiments testing whether shared color, or an enclosing line or spatial contiguity, can overcome the difficulty in preattentive coding of orientation for the virtual line connecting a pair of dots of opposite contrast. None of these grouping aids allowed parallel coding of these bicontrast dot pairs. We conclude that the preattentive coding of orientation is possible only for dots of shared contrast.

3. Priming in feature search; research by Todd Horowitz

Todd Horowitz is completing his doctoral dissertation, investigating spatial attention and inhibition in visual search for feature targets. Posner et al. (1987) showed that locations to which attention was earlier summoned by a peripheral cue were temporarily inhibited after attention had moved to some other location, making them a little harder to attend to again - a phenomenon they called inhibition of return. They used simple displays with one target and no distractors. In my feature integration theory, I proposed a different form of inhibition that could facilitate performance in feature search. The idea was that distractors that differed from the target in some salient feature could be inhibited through links from the relevant feature map to a map of their locations, thus reducing the potential interference they might cause with target detection.

Todd explored these ideas about the processing of distractors in a search task by comparing the latency of detection of a target that appeared in a location that had been occupied by a distractor on the previous trial with one that appeared in a previously empty location. He found evidence for a slight inhibition associated with a previous distractor location. This inhibition appeared to cumulate across successive trials in which a distractor appeared in the same location before the target. He explored the conditions under which it appeared and found that it was independent of whether the distractors were heterogeneous or homogeneous and of whether they resembled or differed from the target. However, it did depend on the subject knowing in advance what the characteristics of the distractors and of

the target would be; it did not appear in an odd-one-out paradigm. The results are most consistent with my hypothesis about feature inhibition. They are important in showing that even when subjects select on the basis of nonspatial features (such as color or orientation), the practical effect is to modulate access to regions of space, damping the flow of information from areas containing unwanted features and boosting the signal from locations exhibiting desired properties.

Preattentive processing of scene-based properties; Research by Beena Khurana

Enns and Rensink (1990) reported evidence that early vision has access to scene-based properties such as three-dimensionality and direction of lighting. In a visual search paradigm with line-drawn stimuli, subjects could use differences in apparent three-dimensional orientation and lighting to distinguish the target cube from the distractor cubes. Control patterns of similar complexity that did not give an impression of depth required serial search.

Given that certain scene-based properties can be detected in parallel, one may ask whether the motion system can also use these properties in solving the correspondence problem. Observers viewed a motion sequence that consisted of four frames, each consisting of two pairs of patterns, interleaved in a circular array. In one sequence, the matching patterns adjacent to each other in successive arrays followed a clockwise path, and in the other sequence it followed an anti-clockwise path. If the two patterns were distinguished by the correspondence process, then motion should be seen in the direction dictated by the sequence of matching frames on that particular trial. If, on the other hand, the correspondence process does not distinguish between the objects, then perceived direction of motion should as often agree as disagree with the presented frame sequences. When objects that are perceived as three-dimensional cubes were presented with two-dimensional control patterns in the above described motion sequence, observers overwhelmingly reported the perceived direction of motion in agreement with the frame sequences. In other words, the correspondence process distinguishes between three-dimensional cubes and their two-dimensional counterparts.

5. Preattentive guidance of attention in patients with neglect, with Marcia Grabowecky and Lynn Robertson.

(See reference # 9)

Preattentive processes, such as perceptual grouping, are thought to be important in the initial guidance of visual attention and may also operate in unilateral neglect by contributing to the definition of a task-appropriate reference frame. We explored this possibility with a visual search task in which patients with unilateral visual neglect (5 with right-, 2 with left-hemisphere damage) searched a diamond-shaped matrix for a conjunction target which shared one feature with each of two distractor elements. Additional grouping stimuli appeared as flanks either on the left, right, or both sides of the central matrix, and significantly changed performance in the search task. As expected, when flanks appeared only on the ipsilesional side a decrement in search performance was observed, but the further addition of contralesional flanks actually reduced the decrement and returned performance to near baseline levels. These data suggest

that flanking stimuli on the neglected contralesional side of visual space can influence the reference frame by grouping with task-relevant stimuli, and that this preattentive influence can be preserved in patients with unilateral visual neglect.

Marcia Grabowecky continued this work with patients in her doctoral dissertation. She explored the influence of the center of mass of blobs or global objects in a display on the apparent shift in reference frame found in the experiment reported above, contrasting it with the effect of similarity at the feature level between flanking stimuli and the search displays. Her idea was that the center of mass of a display may be influenced by the density and distribution of the individual elements it contains. Earlier research has shown that saccades are directed towards the center of mass of a group of elements arrayed in the periphery: thus, saccades to a clearly discriminable target overshoot if additional elements appear beyond them and undershoot if the extra elements are between the target and the fixation point (Coren & Hoenig, 1972). Marcia's experiments supported this account of the grouping effects in the patients, showing effects of density but not of similarity. There may be advantages in having a mechanism that directs the eyes to the center of potential objects, a convenient position from which to produce subsequent, more precise, exploratory movements. This same mechanism is likely to move attention before the saccadic eye movement occurs, (Posner, 1980; Shepherd, Findlay, & Hockey, 1986), increasing the advantage of the subsequent fixation. Marcia showed in normal subjects that the center of mass of stimulus arrays, which influences saccadic eye movements, also influences the movement of attention, revealed by the latency of target detection when attention is necessary to detect those targets.

6. The role of attention in the "shooting line" illusion, with Paul Downing.
(See reference # 16)

When a brief lateral cue precedes an instantaneously-presented horizontal line, observers report a sensation of motion in the line propagating from the cued end towards the uncued end. This illusion has been described as a measure of the early facilitatory effects of visual attention (Allport, 1980). Their hypothesis was that a spatial precue draws attention to its location and results in faster transmission of neural signals from that area than from more distant ones. The gradient of attention produces a gradient of arrival times at motion detectors which mimics the signals produced by real motion. This claim has generated a great deal of interest and of follow-up research in the past few y ears. However, we have found evidence suggesting that the illusion is not caused by attention, but rather is the result of an impletion process which links the cue and the line as successive states of a single object.

In one experiment, we reversed the order of the cue and the line and found that the line appeared to shrink towards the cue rather than expanding away from it. In another we compared the effects of two cues on either side of a central line when these were the only stimuli and when we added a second line to the right or left of the display. When there was only a single central line, it appeared to propagate inwards from each of the peripheral cues, but when the additional line was presented, both lines propagated away from their adjacent cues, as in the

apparent motion displays described by (Ternus, 1939). In a third experiment, we used centrally defined instructions ("attend to the red cue" when a red and a green cue were both presented) rather than peripheral cues to direct attention and found no shooting line illusion, although there was a clear attention effect on probe trials involving a letter discrimination task at the cued location. These and other experiments clearly dissociated the effects of attention from those of apparent motion and showed that the shooting line illusion occurred only in the conditions that also gave rise to apparent motion, and not in those that produced only attentional effects.

II. Feature integration, attention and object perception

In this section, I describe some studies we have carried out on intermediate vision. Many test the ideas of feature integration theory (Treisman & Gelade, 1980; Treisman, 1988; Treisman, 1993) proposing that spatial attention is required to conjoin features in forming representations of objects when the display contains more than a single object.

1. Integrating features within as well as between dimensions. (See references #1 and 3)

During my previous grant period, I had proposed a significant extension of my earlier feature integration theory. The idea was that different features within a single dimension, (for example different colors within the dimension of color or different orientations within the dimension of orientation), are coarsely coded at the preattentive level (Treisman, 1991). They activate separate feature maps for only a few different values, perhaps 3 to 5. In order to make finer discriminations, focused attention is required, because they involve conjoining activity across two of these feature maps within a dimension, in exactly the same way that focused attention and feature integration are required when two features on different dimensions must be conjoined. For instance we would see purple by conjoining activity in the red and in the blue feature maps that comes from the same location in space, or we would see a slightly left tilted line by conjoining activity in corresponding locations in the map for vertical and in the map for left diagonal. I showed that search is slower and looks serial when the target is defined by intermediate values of color and orientation and faster or more parallel when the target is defined by a standard value like vertical or blue that would not require any withn-dimension feature integration. Moreover, illusory targets are reported not only in the usual displays with between-dimension conjunctions, but also in displays containing different features on the same dimensions that would, according to the theory, share the same underlying components.

Duncan and Humphreys proposed an alternative account of my results in terms of their similarity theory of search (Duncan & Humphreys, 1992). They suggested that similar distractors induce a spreading suppression that makes them easier to reject. In order to test their account, I ran a new experiment in which I introduced new distractor elements that should, according to their theory, suppress the distractors without affecting the target. These additional distractors in fact had no effect whatever on the search slopes, ruling out the spreading

suppression account and supporting the predictions of the extended feature integration theory.

2.Spatial attention and feature integration: Evidence from a patient with bilateral parietal damage, with Lynn Robertson and Stacia Friedman-Hill.
(See reference #15)

There is accumulating evidence for some specialization of function between two major visual pathways: a ventral pathway that extracts various features of objects like their color, orientation, texture, and aspects of shape, culminating in the identification of objects in area IT, and a dorsal pathway dealing with the representation of space, motion, and the spatial control of actions. In order to form perceptual representations of particular objects currently in view, with their specific combinations of features in their current locations, the information in these two pathways and these multiple areas must be "bound" together in the correct combinations. Feature integration theory (Treisman & Gelade, 1980) proposed that the binding problem could be solved in multi-item arrays if a "window of attention" were focused on one location at a time. This would temporarily exclude features from unattended objects while a representation was formed of the currently attended object, thus reducing the risk of erroneous bindings or illusory conjunctions. Attention selects within a master map of locations that represents **where** things are without specifying **what** they are.

Patients with bilateral parietal damage resulting in Balint's syndrome have severe difficulties in any spatial localization task. They are unable to point at targets or to report where they are in a display, in terms of either their absolute or their relative locations. They also typically see only one object a a time. Feature integration theory suggests a direct link between the spatial deficit in Balint's syndrome and specific problems in the perception of objects in multi-element displays. The problems it predicts are (1) a difficulty in seeing more than one object at a time; (2) a tendency to see illusory conjunctions of features when two or more objects are presented together; (3) a marked difficulty in selective attention when two or more objects are presented together, and one is cued by a spatial marker or by some other feature like its color; (4) a pronounced failure to detect a target defined by the absence of a feature among distractors which all have that feature, although there is no difficulty in detecting a target defined by the presence of the same feature among distractors which lack it. Normal subjects also show this search asymmetry (Treisman & Gormican, 1988) , but the patients in question should show it in an exaggerated form.

The patient that we studied showed all the predicted deficits to quite a striking degree. For example in early sessions he made 26% illusory conjunction errors, recombining the color and shape of two colored letters (e.g. reporting a red T in a display containing a red X and a green T), even with exposure durations as long as 10 seconds. He was very bad at selecting items cued either by a white bar marker or by their color (red among green letters), making about 30% errors. In a subitizing task, he reported only 1 or 2 elements in displays containing up to 5. He was at chance in reporting whether an X was at the top or bottom of the screen, or above or below an O. He was quite unable to find either a conjunction target (e.g.

red X among red Os and green Xs), or an O among Qs, even given displays with only a few distractors and exposure times of several seconds. On the other hand, he had no difficulty detecting a feature-defined target (red among green or X among Os) or a Q among Os.

Note, however, that there is another medium within which objects can be individuated and features bound: time can potentially function as an alternative to space. We can focus on a particular instant of time and conjoin whatever features are present at that instant in the same way that we can focus on a particular area of space and create an object from the sensory data that occupy that location. If the deficit in patients with bilateral parietal damage results primarily from a loss of the spatial medium for binding, the deficit should be absent when the stimuli are presented sequentially, allowing the use of time as the medium for individuating objects. This was indeed the case for our patient: When tested with a sequence of single items in rapid serial visual presentation (RSVP), he made far fewer conjunction errors on size and shape relative to those he made with simultaneous presentation, whereas control subjects showed the reverse. The result confirms that his problem was not a general difficulty in binding features to objects, but a specific deficit in the integration of features on the basis of shared location.

All these difficulties were manifest in tasks requiring explicit reports of consciously perceived objects. However, tasks that tap implicit spatial relations or conjunctions of features at early levels in the visual system might reveal information of which the patients are not consciously aware. The patient was tested in a spatial version of the Stroop task in which he was asked to read the words "up" or "down" presented either at the top or the bottom of a rectangle. Although he was close to chance in naming the locations of the words, his reading was systematically delayed when the word was presented in a position that was inconsistent with its meaning, e.g. "up" at the bottom of the rectangle.

2. Relations between feature identification and localization

We have previously shown that in conditions of divided attention subjects can identify feature-defined targets significantly better than chance even when they mislocalize them. Feature information seems to be partly independent of location information. However, most of the location errors when the feature is correct were to adjacent locations. One possibility in that features have coarsely coded locations attached as an integral part of their representation (Cohen & Ivry, 1989). Another possibility is that attention can be coarsely focused very rapidly on one half of the display or the other, giving the rough area in which a feature is located. In order to test these alternatives, we manipulated the focus of attention. In one condition, subject spread their attention across the display to identify two digits, one on each side of the colored distractor and target bars. In the other conditions the digits appeared together, adjacent and more peripheral than one of the colored bars, following a brief peripheral cue to their location. We compared the interdependence of feature identity and location for items in the three locations adjacent to the digits and in the five more distant locations. We found little difference between the near and the far locations, or between either of these

and the previous divided attention condition. However, we may not have succeeded well in controlling attention, since our subjects made a large number of errors in reporting the digits. We plan to try a more salient cue and test the digits on a larger proportion of trials.

2. Integration of features within or across dimensions; research by Beena Khurana and Marcia Grabowecky

A set of experiments on feature integration of within-dimension conjunctions (color-color conjunctions) has been completed. They indicate that the attentional cost of processing within-dimension conjunctions lies not in an inherent bottleneck on the transmission of information from feature modules, (as suggested by Wolfe et al. 1990) but rather in the spatial separation of features. These experiments also reveal that attention may operate using feature inhibition that is limited to the space occupied by the individual features. This inhibition does not automatically spread to other parts of the visual object that are occupied by the individual features. In other words, the inhibitory processes in search may act at the spatial resolution of features and not whole objects.

3. Occlusion inferences and feature integration; research by Beena Khurana

Beena Khurana completed her doctoral dissertation on the integration of shape and color in the perception of three-dimensional objects. She found that occlusion structures are available pre-attentively and can modify the subsequent synthesis of other features such as the color of contours. Contours which typically create a strong occlusion structure were employed. The colors of the contours were such that they were consistent either with the occlusion structure or with a mosaic interpretation. The contours of the occlusion-inconsistent patterns were more likely to be seen in the color of the occlusion-consistent pattern under conditions of attentional overload. Experiments with two-dimensional control stimuli showed that the constraint imposed by the occlusion structure operates not at the level of local line continuity but rather at the level of global figural occlusion.

The stimuli used in the above experiments can be analyzed in terms of color and luminance information. The occlusion-consistent and the occlusion-inconsistent stimuli are indistinguishable through luminance in that they are both interpreted as occlusion structures. Only the color information differs. The findings suggest that the perceived colors are affected by the three-dimensional structure signaled through luminance information. Beena also showed that the same spatial patterns defined by equiluminant contours did not give rise to the color illusions. These experiments address the current debate in Neuroscience about the distinction between the magnocellular pathway (luminance) and the parvo-cellular pathway (color), and they explore the perceptual implications of the neural independence of on and off pathways in the visual system.

III. Visual perception and memory for novel objects seen with and without attention

The research in this section explored the process of seeing without

identification. We hoped to bring out a distinction between object types - the stored descriptions or models of previously seen objects to which we match present stimuli, - and object tokens - the temporary representations which mediate the perception of a particular stimulus, whether known or unknown, in its current color, illumination, distance, viewing angle and orientation (Kahneman & Treisman, 1984). We used novel stimuli, usually seen without attention and once only, in order to minimize any contribution from topdown type activation. We used indirect priming measures of implicit memory, as well as explicit recognition, to see what kinds of memory representations are formed.

1. Novel shapes in implicit memory, with Brett De Schepper.
(See references # 12 and 13)

The task we used to explore the formation of object tokens was the negative priming paradigm, first developed by Greenwald (1972) and later elaborated by Neill (1977) and by Tipper and his colleagues (Tipper, 1985; Tipper & Driver, 1988). Negative priming is shown when a stimulus which was irrelevant on one trial becomes the relevant stimulus on the next. The switch often results in a slower response than is made to a control stimulus that was not previously unattended, as if the irrelevant item had been inhibited to prevent it from competing for response. The inhibition then lingered into the next trial and had to be lifted before the new response could be made.

In a series of experiments, we tested whether a novel object with no pre-existing representation in memory would show negative priming, in the same way as familiar letters or pictures. This result would suggest that episodic tokens are formed on a trial by trial basis to represent each current, unfamiliar object, - even when it is not the relevant item controlling the response. We used novel forms like those used by Rock and Gutman (Rock & Gutman, 1981), in a same/different matching paradigm in which subjects decided as quickly as possible whether the green shape in an overlapped red and green pair matched a white shape presented separately to the right of the pair . We found a significant negative priming effect when the unattended (red) shape on one trial became the attended (green) shape on the next trial. Thus, negative priming is not restricted to familiar, meaningful or namable object types.

We then tested how long this interference lasts, in order to measure the persistence of the memories. We found that it continues undiminished across at least 200 intervening trials (more than 200 intervening shapes). The effect usually appears in the medians as well as the means, demonstrating that at least half the shapes contribute to the effect; thus it does not reflect perfect storage of just a few memorable instances. In another series of experiments we varied the time delay (as opposed to the number of intervening trials) between the prime and the probe trials, and found evidence that the traces last for at least four weeks. About two thirds of subjects showed negative priming and one third showed facilitation from an unattended novel nonsense shape, presented in the same location as the attended shape. The priming is stronger for shapes that have never been seen before than for shapes presented repeatedly in the course of the experiment, and the priming for familiarized stimuli disappears almost immediately. Repetition

increases the ability of subjects to ignore an unattended shape, but has no effect on negative priming. Priming at delays longer than a few trials seems to be about the same for attended and for unattended novel stimuli. Negative priming for novel shapes is removed by a single trial in which the previously unattended shape is attended. Explicit memory is non-existent for unattended shapes, but above chance after a single presentation for attended ones. Unlike implicit memory for the same shapes, memory for attended shapes does increase substantially with repetition.

The main conclusions suggested by these findings are as follows: (1) Attention is not needed to establish a detailed representation of a novel shape. New object tokens are established automatically and on the fly during performance of a matching task on a different set of stimuli (at least for displays containing only two or three objects; see below for a discussion of load effects in implicit memory). On the other hand, attention **is** needed to form explicitly retrievable traces. (2) Memory tokens of novel unattended shapes last at full strength and specificity across 200 intervening trials using very similar shapes, and persist for delays of several days or weeks. The unique shapes are preserved without loss for at least half the set of 270. This one-trial learning of novel shapes suggests a surprising combination of plasticity and permanence in the visual system. (3) A minority of subjects show facilitation rather than negative priming when a previously unattended shape requires attention. The individual differences may reflect greater or lesser interference from unattended stimuli (shown, for example, by differences in error rates in the motion task), or differences in the strategy used in the matching task (active tagging and suppression of the unattended shape versus parallel processing of the composite stimulus). These individual differences suggest that the inhibition attached to the memory trace may be separable from the shape to which it is attached. Earlier results have shown a reversal from negative to positive priming when a single item is presented on the probe trials (Lowe, 1979; Tipper & Cranston, 1985), consistent with the idea that both components are present in the negative priming paradigm. We have found the same with our shapes. (4) Explicit memory is at chance for unattended objects, better for attended objects seen once only, and much better for repeated attended objects. The vagueness and confusion of explicit memory for both attended and unattended stimuli seen only once contrasts strikingly with the very specific traces revealed by the implicit measures.

The results converge on the idea that visual patterns, (at least those that potentially conflict with similar attended stimuli occupying the same general area), are automatically registered and stored in some lasting but implicit form of memory, perhaps as traces within the perceptual system including areas V4 and IT. These token memory traces are set up within 700 ms., and they last at least a month. Together with each token is stored one or more "action tags" specifying its response relevance. These action tags may decay or disappear independently of the shape itself. Attention and multiple repetitions are needed to make the tokens explicitly retrievable, but not to strengthen the traces themselves and not to increase the probability that they will be retrieved implicitly when a matching attended stimulus is next presented. We may speculate further that explicit

memory traces differ from implicit ones not in the traces themselves and not in the brain system that contains them, but in the mechanisms which make them consciously accessible.

2. Task specificity in negative priming, by Brett De Schepper

Brett completed his doctoral dissertation, which consisted of the study described above, which was done jointly with me, together with the two experiments which follow. The aims of the new experiments were (1) to test a different measure of implicit memory for unattended stimuli - namely whether unattended presentations of shapes cause a mere exposure effect, leading to more favorable ratings in an aesthetic judgment task; (2) to see whether negative priming is task-specific, or whether the implicit memories that are created in an aesthetic rating task also lead to negative priming in a same-different matching task. Subjects were shown the same overlapped shapes, but rated the shapes for their aesthetic quality rather than matching them. In the same experiment Brett looked at the effects of repeating the same unattended shape nine times in succession before switching it to the attended role. He found significant negative priming in the response times for the aesthetic ratings, but not in the numerical values of the ratings themselves. The aesthetic rating task, like the matching task of the earlier experiments, apparently creates implicit representations of unattended stimuli that can be inhibited when they compete with others to be attended. The inhibition slows access to those shapes on a subsequent trial without changing the subjects' ratings of their artistic merit. As in our previous experiments with unattended presentations, the number of unattended repetitions had no effect upon the magnitude of the negative priming.

The second experiment examined whether priming transfers between the same/different matching task and the aesthetic rating task when they share the same stimuli, or whether it is specific to the experimental context in which the shapes are perceived and acted upon. Subjects were presented with displays of green and red overlapping shapes and, on matching trials, white comparison shapes. If only the green and red shapes appeared, without the white shape, they were to give an aesthetic rating of the green figure while ignoring the red figure. If the white shape appeared along with the overlapping pair, they were to compare the green and white figures and press keys labeled "same" or "different". They were tested with each combination of within and across task priming pairs (match-match, rate-rate, match-rate and rate-match). There was significant negative priming for both within-task conditions, replicating the earlier results. However, for the between-task conditions, only the "matching->rating" condition showed any effect and it was 50 ms of facilitation rather than of inhibition. The perceptual representation that was set up in the "matching" prime must have carried over into the "rating" probe facilitating its re-perception. However, the inhibition appears to have been specific to the task and did not carry over. This might be expected if the inhibitory effect (the "action tag") is tied more to the task than to the stimulus. When the task switched from "matching" to "rating", the inhibition no longer applied but the perceptual facilitation remained and decreased reaction times.

The "rating->matching" priming condition was not significantly different from its control condition. Since the previous experiment had shown within-task negative priming in the "rating" task, a representation of the distractor must be set up somewhere in the perceptual system. However, it seems not to interfere with or benefit the processing of the same shape in the "matching" task. One possible account of the asymmetry between the "matching->rating" and the "rating->matching" combinations rests on the idea that perceptual representations may be set up at a number of different levels. The asymmetry could result if the internal representations from the "matching" trials are shared by both tasks and are able to create facilitation. On the other hand the representations used in the aesthetic ratings may reflect higher level processing, perhaps based upon global shape characteristics. The higher level representations need not help at all with the perceptual processing involved in the matching task.

It appears that negative priming is highly specific to the task being performed upon the shapes and that changes in the task with the same stimuli can dissociate the facilitatory effect from the inhibitory effect. The facilitatory effect appears to remain intact across some changes in the task performed (but not all), whereas the "action tag" seems to be bypassed entirely. This difference between the two priming effects would be expected if the facilitatory effect operates primarily upon the stimulus (which doesn't change) and the inhibitory effect depends upon the task (which does change). Considering the longevity of the effects we found, it is good that ignored objects are only inhibited within the appropriate context. Otherwise, everything that was ever ignored in any context would end up inhibited and difficult to respond to quickly, which could be maladaptive in the real world.

3. Negative priming with figure-ground stimuli and with occluded shapes: Evidence suggesting early 2D representations for unattended stimuli, with Brett De Schepper and Anne Pugh.

In all the experiments so far, the attended and the unattended shapes have competed while remaining independent entities, with potentially equal perceptual status, except that one was selected to control the response. A different kind of competition might arise when one of two shapes has the status of figure and the other is seen only as the background. The "shape" of a background is typically not consciously represented in perceptual experience, not just because it is unattended but because its contour is allocated to the figure and given a different interpretation. For example, a curve must be seen as either convex or concave, and if it is convex in the figure it will be concave in the background (or vice versa). In this case, we thought that inhibition might be unnecessary; the shape of the background would simply not be represented; it would not exist as such for the perceptual system.

To test this possibility, we used 120 different figure-ground pairs consisting of squares vertically divided roughly in half by a "randomly" hand-drawn contour. The squares were presented against a gray background and the area to one side of the border was filled in black and the other in white. Trials were organized in pairs, alternating a prime display and a probe display, or two equivalent but

unrelated control pairs. The primes were figure-ground stimuli and the probes were two separate figures, one of which could be the unattended half of a previous figure-ground stimulus. Subjects attended and responded to the black figure in the figure-ground prime pair and the white one in the separated probe pair. The side on which the black figure was presented was randomized across pairs of trials but consistent within prime-probe pairs. The task was to match the relevant shape to the single shape below (which always matched its color). We also tested 15 of the subjects with a final catch trial of recognition and found that their performance on the background shape was at chance. Memory for the figure was slightly better than chance (6/15). Again there seems to be no explicit memory whatever for the "shape" of the background.

We found significant negative priming when the background shape from the prime display became the attended figure in the probe. Thus it seems that negative priming in this paradigm is attached to representations formed at an early level, before the contour is interpreted as the boundary of the figure rather than of the ground. At this early level, the shared contour is attached both to a representation of the shape that is consciously seen as the figure, and also to a representation of the shape that is not seen at all because it is interpreted as the ground which continues behind the figure.

In a related experiment, we looked for more evidence about the level of processing reached by the unattended shapes in negative priming. We showed pairs of shapes in which a red shape appeared to occlude a green shape. The question that interested us was whether the representation differs when subjects attend and when they do not attend to the occluded shape. (Nakayama, Shimojo, & Silverman, 1989) have suggested that occlusion is registered quite early in the visual system, on the basis of bottom-up cues like the presence of t-junctions. If this is the case, then even without attention subjects might store the completed version of the occluded shape, as if it continued behind the occluder. But if the representation of the unattended shape is confined to an earlier level of processing than the attended one, subjects might store simply the two-dimensional jigsaw pattern.

On prime trials in one experiment, the subject attended to the occluding red shape. On probe trials, the two shapes were separated, and the subject attended to the green. On half the negative priming trials, the green shape in the probe was the jigsaw version of the apparently occluded green shape from the preceding trial, and on half it was the completed version (using a simple curve to join the points where the occluder interrupted the contour of the apparently occluded shape). We found negative priming only with the jigsaw version. There was none at all with the completed version (-2 ms). In contrast, in the next experiment, another group of subjects attended to the occluded green shape instead of the occluding red shape in the prime trials, and again to the green shape in the probe trials. These subjects showed facilitation (repetition priming) for the completed version, but none for the jigsaw version. There was a negative correlation across subjects in both experiments, between priming for the jigsaw and priming for the completed shape. It seems that the stored token represents only one of the two interpretations of the occluded shape, and only this one has a priming effect. For

the attended shape, the jigsaw probe actually showed some interference rather than facilitation (+19 ms), as if that interpretation had been suppressed when the shape was previously attended, (although this interference did not reach significance). The dissociation between attended and unattended shapes again suggests that the unattended shapes are stored at an earlier level than the attended ones, perhaps in a fairly raw sensory form, and that they are interpreted in depth only when they receive attention.

4. Priming and visual memory for events

(Kundera, 1990) claims that memory consists of snapshots rather than moving pictures. Treisman, Russell, and Green (1975) showed iconic memory in a partial report task for the direction of motion of circling dots that was equivalent to iconic memory for static stimuli equated in difficulty for total report. At least an evanescent memory trace does seem to be laid down, directly representing motion as well as static stimuli. We have recently begun using the negative priming paradigm to explore implicit visual memory for dynamic events as well as for static objects. Instead of pairs of static shapes, we present pairs of moving dots. In one experiment, a green dot and a red dot appeared superimposed (as a red and green striped dot) in the same location and then moved on separate, randomly generated, 8-segment journeys in an imaginary square grid, away from the initial location and back to it, taking 2800 ms for the complete trajectory. The motion was too slow for visual persistence to give any direct impression of the figure as a whole; the appearance was of two single dots moving. The task was to track the green dot and to decide whether a static white shape, presented to the right of the display, immediately after the motion was completed, exactly matched the trajectory that the green dot followed.

This is a difficult task and only about half the subjects could keep their errors below 30% in all conditions. For these 18 subjects, we found facilitation in reaction times, when the path that the green dot followed exactly matched the path that the red dot had followed on the immediately preceding trial, relative to the control condition in which a new, randomly generated path was shown. The 19 subjects who had more than 30% errors in one or more conditions showed interference, averaging 38 ms (significant, $p<.05$). The priming did not differ on "Same" and on "Different" trials, so it did not depend on a match to the static white shape presented on "Same" trials. Perhaps we can interpret the group differences as differences in how much interference the red dot caused: The group with high errors may have suffered more interference and therefore may have tried to inhibit the irrelevant path, while the group with lower errors may have found it easy to ignore the irrelevant path without actively suppressing it. These subjects therefore registered the motion path without attaching any inhibition to it, and showed facilitation when it reappeared in the attended role in the next trial. We are testing this interference hypothesis by seeing whether subjects who show negative priming show more benefit than subjects who show facilitation when the irrelevant dot is removed.

The significant priming effects, both positive and negative, suggest that memory traces are laid down for unattended events as well as for unattended

objects. The motion trajectories were apparently stored after a single presentation and retrieved when they were re-presented, again with no awareness on the part of the subjects.

5. Levels of attentional inhibition in negative priming; research by Brett De Schepper, Meg Wilson, Kathy O'Craven, and Beena Khurana.

Several of my graduate students devised a search version of the negative priming paradigm to explore what aspects of a perceptual display can be inhibited; specifically, whether the process of selection may leave residual inhibition not only on the responses, but also on the perceptual features used for selection. In order to vary the selection cues across trials, they used an "odd-man-out" task with multi-item displays. Subjects selectively attended and responded to the "odd-man-out" in a display of six items and ignored the other items. Either the selection features or the response features of the ignored items could then be repeated in the attended item of the subsequent trial.

In one experiment, they directly tested the hypothesis that negative priming may occur for features that are used for selection only and are independent of responses. Subjects selected the "odd-man-out" on the basis of one feature and then responded to it by naming a different feature. Some subjects selected the "odd-color-out" and named the letter in the odd color; others selected the "odd-letter-out" and named the color of the odd letter. They showed significant negative priming for both colors and letters, although the effect was larger for letters than for colors. Since the attributes that were primed in this experiment were used only for selection, this result suggests that negative priming may not be simply due to "selection for action" from among competing responses. The act of selection seems to leave residual inhibition on perceptual features used only for selection.

Another question that the students attempted to answer in this study was whether perceptual features that are completely irrelevant to the task are also inhibited. To examine this possibility, they ran a series of experiments in which a third attribute was introduced to be used for selection. The other two dimensions (colors and letters) could then be used to test for priming of the response and priming of the irrelevant dimension. The selection attribute was letter size in one experiment, target flicker in another, target motion in another, and a target marker in another. The results of these experiments are inconclusive so far; the irrelevant attributes showed negative priming in some cases but not others.

IV. Object tokens in perceptual priming, learning and search automatization

We continued the research begun on my previous grant, exploring the effects of initial perception on later re-perception in search tasks for feature and conjunction targets. The aim is to explore how the direction of attention and the nature of the task determine the nature of the memory traces formed by stimuli in multi-element displays. When we look at a scene, we have the option of dividing attention to process it globally, or of focusing attention on one object at a time. We suggest that when attention is divided, all the features within the attention window are processed in parallel, but only their global layout is available. The

presence of a single unique feature will "pop out" of a display, but it may be poorly localized and its particular conjunction of other features will not be available until attention zooms in to that element alone. When attention is focused on individual elements, on the other hand, their features will be conjoined and each item will be individuated. This should affect the memory traces that are formed and the nature of the learning that takes place. The research in this section explored some effects of the type of perceptual processing on the memory traces that are evoked, both in long term practice effects and in short term repetition priming.

1. Learning contingencies in feature and conjunction search , with Amy Hayes (See references #4, 5, and 18)

When extended practice in search is given, substantial changes occur. Complex shapes may eventually appear to be detected automatically (Vieira & Treisman, 1988). On the other hand there is very little transfer from this learning to other tasks using the same overlearned shapes. We suggested that the automatization we observed might depend on specific object tokens, traces left by each experience of a particular target display, as in Logan's exemplar model of skill acquisition (Logan, 1988). In conjunction search, attention is directed to an object and all its features are automatically integrated with their location and with each other. On the other hand, in feature search no individuated object tokens are needed. If skill acquisition depends on reactivating earlier object tokens, we therefore expect more specificity in conjunction than in feature search.

The experiments all shared the following design. The task was visual search for any one of three or four targets among six or eight distractors (non-targets) presented in a circular array. On each trial there was either one target present or none and subjects pressed one key for target present and one for target absent as quickly as they could. They were tested in repeated sessions on the same experiment, for between 5 and 13 hours.

In one experiment subjects looked for four targets, defined either by separate features or by conjunctions of features. The feature targets were blue, pink, vertical and horizontal bars among purple and turquoise left and right diagonal bars. The conjunction targets were a pink P and Q and a green R and O among green P's and Q's and pink R's and O's. The mean search latencies were, as usual, much longer for conjunction than for feature search, but we remove this main effect by giving all the priming effects as a percentage of the latencies on the equivalent control trials.

In order to test the effects of initial perception on re-perception and automatization, we introduced contingencies between some of the targets and their locations. We could then observe whether these contingencies would be reflected in the measures of learning with practice. The prediction was that the contingencies would be learned and affect performance only when focused attention was required for the search. Unless separate object tokens are formed for past targets and remain available across multiple trials, the correlation between the targets and their incidental features should have no effect on performance because they would leave no individuated traces in memory.

In each case, two of the four targets were associated with particular locations in which they appeared on 75% of trials, while the other two targets appeared in randomly selected locations. We found a large difference between conjunction and feature search in the specificity of what was learned. As predicted, there was a very large effect of location consistency on conjunction search, which increased across sessions, and a much smaller effect on feature search, which actually decreased across sessions. Despite the very large differences in reaction time, no subject noticed the location consistency in the conjunction condition before the seventh session at the earliest. It seems that the benefit of the location consistency reflects an implicit form of memory rather than resulting from a conscious strategy.

In two further experiments, we looked at contingencies between the targets and other irrelevant features besides location, to see if we could find differences in specificity on other dimensions as well. We associated one target with a third irrelevant feature and the other with a particular area of the display. In this experiment, we found a consistency benefit of 8% for the feature-biased target when it appeared with its associated feature, and a benefit of 13% for the location-biased target when it appeared in its associated location, both significant. Both were specific to their associated target; the effect of appearing with the biased feature or location of the other target was zero or even negative. On the other hand, in a similar search experiment with feature rather than conjunction targets, the consistency benefit of associated features averaged only 1.5% and had disappeared by the third session.

Finally in two more experiments, we looked at the effects of consistency of the distractors rather than the targets. Again, the effect was much larger in conjunction than in feature search, as it should be if each distractor is attended in order to ensure that its features are not conjoined to fit the target definition.

The results support the idea that the effects of practice in the automatization of search are mediated by an accumulation of specific memory traces. The task required during perception has a large effect on what is learned. When attention must be focused to set up separate individuated object tokens specifying how the features are conjoined, the speeding of responses depends on the degree of match to the most frequently experienced objects. When parallel processing with divided attention is sufficient, the contingencies have little or no effect on automatization. Subjects presumably form a global object token for the display as a whole, representing the presence of the particular target feature without individuating the element that carries it.

<u>2. Short term repetition priming in search, with Amy Hayes</u>

(See references # 5, and 18)

Another implication of the idea that automatization reflects the accumulation of specific object tokens is that a new memory trace for the current appearance of the target is formed on every trial. If this is the case, it should be possible to probe for its presence immediately after each particular experience by looking for content-specific priming of each trial on its immediate successor. We expect to find similar effects of experimental variations on this short term priming

measure and on long term learning in skill acquisition.

To test this idea, we used the same search data, but looked at each trial as a function of what was repeated from the preceding trial. It could be the same target in a changed location, the same location with a changed target, or the same target in the same location, or it could be a completely different target and location. We compared the latencies on each type of repetition trial to those on control trials, which were identical except that they followed a trial on which no target was presented, so no repetition benefit could occur. This allowed us directly to compare the specificity of the long term learning with that of the short term repetition priming in the same experiments.

In the first experiment I described (with location-biased pink and green letters in conjunction search and colored bars in feature search), we found a significant short term priming benefit for exact repetitions of both target and location, averaging 15% for conjunctions and 10% for feature targets. When the same target was repeated in a different location, the benefit was halved and was no longer significant for the conjunction targets. When the same location was repeated but the target changed, the benefit disappeared altogether and in fact became a slight but non-significant cost for the conjunction targets. Thus in this experiment, the short term, trial-to-trial priming seems to be fairly specific, particularly for conjunction search: Both the identity and the location must be repeated to ensure that the preceding target token is re-perceived.

In the experiments in which we introduced consistencies with irrelevant features as well as locations, we again found evidence of specificity in the short term priming for conjunction search, and this time none at all for feature search. There was a significant benefit in conjunction search only when the target was repeated with the same irrelevant feature or in the same location as on the previous trial. In feature search, on the other hand, we got the same benefit from repeating the feature targets whether or not their irrelevant features were changed. Thus the task required during perception seems to determine whether separate object tokens are established. Trial-to-trial priming occurs both for a target feature in feature search and for a target conjunction in conjunction search. However it seems to depend on individual object tokens in conjunction but not in feature search.

In the search tasks described above, the results were very similar for short term priming and for long term learning, as they should be if the same specific object traces are involved. However, there were also some intriguing differences, suggesting possible changes in the mode of retrieval over time. For conjunction targets, there seemed to be a change between the short and the long term measures in what produces a cost. A mismatch on location when the location-biased target appeared in an unexpected location was very costly in the long term measure, whereas changing the location produced no cost in trial-to-trial priming. On the other hand, in short term priming, there was a slight (though not significant) cost of changing the target when the location was repeated.

This pattern of costs and benefits suggests an asymmetry between the retrieval cue and the content of what is retrieved. Early on, the location of the object is a powerful cue for retrieval. If the currently attended location matches

that of the previous target, its content is retrieved and produces a benefit when the targets match and a small cost if they do not. Once a token has been retrieved, however, the location information stored with it may also become salient and substantially delay the response if there is a mismatch with the location of the presently attended object, or speed it up if both target and location match. Thus, in long term learning, subjects directly retrieve information about targets, including where they are likely to appear; they are less likely directly to retrieve information about locations, specifying which objects each location is most likely to contain.

Overviews and theoretical papers

In addition to these experimental research projects, I wrote two theoretical and empirical overviews of my research on attention and feature integration (see references #6 and 8), a theeoretical and empirical paper on the idea of object tokens, (see reference #5), a commentary on some papers proposing different approaches to the problem of object representations (see reference # 7), and two short theoretical papers (see references # 11 and 14) replying to articles by Van der Heijden, in which I argue (a) that the evidence for attentional effects on perception as well as on response selection is strong, and (b) that modularity of neural processing creates a binding problem for which feature integration theory offers a possible solution.

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Publications and papers submitted on research supported by this AFOSR/ONR grant (copies enclosed).

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18. Treisman, A., & Hayes, A. Location and feature specificity in priming and automatized search. In preparation.

19. Treisman, A., De Schepper, B., & Pugh, A. Preattentive representations of figure-ground pairs and of occluded figures: Evidence from negative priming. In preparation.

In addition, my graduate students have several papers on their dissertations and other independent research either submitted or in preparation.

Invited addresses, papers, and talks

Nov. 1990. Invited paper at Symposium on "Varieties of Automaticity," Psychonomic Society, New Orleans.

Nov. 1990. Colloquium at N.I.H., Bethesda.

Dec. 1990. Colloquium to Oxyopia series, U.C. Berkeley.

June 1991. Invited talk to conference on 'Recent advances in the analysis of attention,' Davis, California.

August 1991. Invited talk to Symposium on "Visual attention and object recognition" at IBRO World Congress of Neuroscience.

August 1991. Distinguished Scientific Contribution Award address to American Psychological Association meeting, San Francisco.

Sept. 1991. Invited paper to Festschrift for Donald Broadbent, Oxford, England.

Oct., 1991. Colloquium at Columbia University.

Oct., 1991. Invited lecture to Seventh Annual Meeting of the International Society for Psychophysics.

Nov., 1991. Talk (with Brett De Schepper) on "Novel visual shapes in negative priming" at 32nd Annual meeting of Psychonomics Society, San Francisco.

Dec., 1991. Colloquium at New York University.

Jan., 1992. Seminar at Russell Sage Foundation.

Feb., 1992. Colloquium at University of Pennsylvania.

Invited lecture to Lower Ontario Visual Conference

March, 1992. Colloquium at Rutgers University, Newark.

April,1992. Colloquium at M.I.T.

May, 1992. Colloquium at Princeton.

Poster (with Todd Horowitz) at ARVO meeting, Sarasota, Florida.

July, 1992. Invited paper to symposium on Attention, International Congress of Psychology, Brussels, Belgium.

March 1993. Talk at Interval Research Corporation, Stanford, CA.

May, 1993. Talk at ARVO, Saraasota, Florida.

Invited paper to BASICS Conference, Banff, Canada.

December, 1993. Colloquium at Rutgers University, New Brunswick

February, 1994. Colloquium at SUNY, Stonybrook

March, 1994. Invited paper to Israeli Binational Workshop on Cerebral cortes and object perception, Jerusalem.

March, 1994. Invited paper in Symposium on attention, Cognitive Neuroscience Society, San Francisco.

May, 1994. Talk at N.E.C., Princeton.

July, 1994. Association Lecture, International Society for the Study of Attention and Performance, Tokyo, Japan.

November, 1994. Talk with Brett De Schepper to annual meeting off the Psychonomic Society, St Louis, Missouri

January, 1995. Invited speaker at the Vancouver Cognitive Science Conference on Attention

March, 1995. Seminar to Neuroscience group, Hebrew University, Israel

March, 1995. Distinguished lecture to the Eastern Psychological Association meeting, Boston.

April, 1995. Fred Attneave Memorial Lecture, University of Oregon

May, 1995. Harold Schlosberg Memorial Lecture, Brown University.

May, 1995. Talk with Paul Downing at meeting of the Association for Research in Vision and Opthalmology, Fort Lauderdale.

July, 1995. Talk to Experimental Psychology Society, Birmingham, UK.

In addition, Beena Khurana, Marcia Grabowecky, Meg Wilson, Brett De-Schepper, Todd Horowitz, and Kathy O'Craven have all given at least one talk or poster on their research supported by this grant, at ARVO meetings or elsewhere.